An Analysis on the Causes of Head-on Collisions through Long-term Data Collection of Near Miss Incidents at Unsignalized Intersections

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1. Introduction
According to the latest Japanese collision statistics, head-on collisions are the second most frequent type of collision on all roads. Additionally, from the perspective of applying cooperative vehicle-highway technology, head-on collisions, to which it is difficult to provide standalone vehicle services, should be the first to consider. There are limits to employing existing countermeasures in reducing head-on collisions, and as the recognition becomes common that services to provide information just before a collision are more effective, research has been continued from last year on a feasible and easily diffusible approach for a head-on collision prevention support service for unsignalized intersections. As part of that research, this paper establishes hypotheses for the causes of head-on collisions and examines those hypotheses using collected data. Collecting near head-on collision data on actual roads during a long-term time frame has increased the amount of data and helped to improve the accuracy of the evaluation. This objective data regarding immediate pre-near miss incident circumstances will be used to clarify the factors of head-on collisions. Utilizing the collected data, an approach for a head-on collision prevention support service will also be presented.

2. Establishing Hypotheses
According to collision statistics, approximately 3/4 of the human-related causes of head-on collisions at unsignalized intersections, where a large number of head-on collisions occur, are due to “negligence of safety confirmation.” Additionally, it appears that drivers are not observing approaching traffic to an appropriate degree as at times, their way of watching other vehicles at intersections is halfhearted, they carelessly do not look, or assume a car is not coming. We establish the first hypothesis as follows.

Hypothesis 1: In a head-on collision, the driver does not properly keep an eye on an approaching vehicle because they assume nothing is coming or they carelessly fail to check.

If hypothesis 1 is confirmed, it can be determined that boosting caution and reducing collisions is possible by showing careless drivers vehicles they are to intersect paths with, or notifying them of those vehicles.

Hypothesis 2: It is highly expectable that a head-on collision safety support service would be greatly effective if approaching vehicles were made easily visible or drivers were notified that they are "coming."

By notifying drivers without right of way of “oncoming” traffic, they will stop at the intersection and take proper caution. The driver should confirm the position and speed of an approaching vehicle with their own eyes after stopping, and the next hypothesis has been established accordingly.
Hypothesis 3: Information provided to the driver, even if only limited to the existence of a vehicle that they are to intersect with, can help the driver to drive more safely.

Hypothesis 3 simplifies the function of the service and is considered necessary for realizing a reduction in its cost.

3. Data Collection of Near Miss Incidents
(1) Target Intersection for Collecting Data
The intersection used for collecting data is an unsignalized intersection located in Kakogawa City within Hyogo Prefecture, and has a relatively large amount of traffic to its size. The intersection’s configuration is represented in Figure 1.

Vehicles entering the target intersection on the road without right of way (the vehicles in the bottom left driving toward the top right of Figure 1) lack sufficient visibility on both the left and right due to buildings or fences. Drivers are able to maintain appropriate visibility to both the right and left when the front of the vehicle is extended into the intersection; however, because the road is at an angle (approximately 52 degrees), it is necessary for the driver to make a large movement of the head to the left for ensuring safety. The actual number of vehicles recorded during the afternoon at this intersection was about 360/hour for vehicles traveling in the lane without right of way (entering from the bottom of the Figure 1) and about 230/hour for vehicles traveling in the lane with right of way (entering from right of the Figure 1).

(2) Collection Method
Continuing on the previous fiscal year, data was collected and recorded with the cooperation of West Japan Railway Company and local residents with multiple cameras being positioned at sides of the intersection to photograph the position of vehicles in both the lanes without right of way and those lanes with right of way, and the overall intersection. Moreover, the rear brake lamp of vehicles in the lanes without right of way was photographed and recorded from a separate position. The overview of the data collected is represented in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Collection Period</td>
<td>191 days from March 21 to September 27, 2006</td>
</tr>
<tr>
<td>Collection Time</td>
<td>About 6:00 a.m. – 6:00 p.m. (based on a timeframe that allows light for the camera and changes by season) (recording media changed by hand every two weeks)</td>
</tr>
<tr>
<td>Target Vehicles</td>
<td>Category 1 (vehicles without right of way) are 4-wheel vehicles. Category 2 (vehicles with right of way) are 4-wheel vehicles, 2-wheel vehicles, and bicycles.</td>
</tr>
</tbody>
</table>
Figure 2 displays the intersection and where cameras were placed.

Fig. 2: Intersection (from road 1)

(3) Collected Results

Table 2 represents the number of near miss incidents recorded in the 191-day period from March to September 2006.

<table>
<thead>
<tr>
<th>Event</th>
<th>Number</th>
<th>%</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total vehicles on roads (all roads)</td>
<td>1190694</td>
<td>100%</td>
<td>Within collection period *1</td>
</tr>
<tr>
<td>Collision</td>
<td>9</td>
<td>0.0008</td>
<td>All due to neglect of safety confirmation</td>
</tr>
<tr>
<td>Near miss incidents (average-severe)</td>
<td>247</td>
<td>0.02</td>
<td>Category 1 vehicles, combined roads 1 and 3</td>
</tr>
<tr>
<td>Near miss incidents (average-severe)</td>
<td>104</td>
<td>0.008</td>
<td>Category 1 vehicles on road 1</td>
</tr>
</tbody>
</table>

*1: This figure is a conversion of a single week’s data into the 191 day period from March 21 to September 27.

Figure 3 clarifies the directions of traffic in the intersection and defines “near miss incidents.”

Definition of “near miss incidents”: The situation when the driver must take immediate driving measures that is against their initial intention. Specifically, it is when the driver brakes suddenly right after resuming acceleration following a stop or slow down.

85% of near miss incidents were due to neglect of safety confirmation while 15% were due to disregard of surrounding activity. However, the figure for near miss incidents due to neglect of safety confirmation includes a small number of speed misconception and other reasons. Additionally, it is possible that a portion of the figure for near miss incidents due to disregard of surrounding activity overlaps with that for neglect of safety confirmation.
4. Analyzing Near Miss Incident Data

Near miss incidents were analyzed in regards to the ratio of time the driver spent visually confirming each direction just before an intersection, their visual confirmation behavior, and the vehicle’s approach and deceleration at the intersection.

(1) Visual Confirmation Time

Centered on the direction a driver of a category 1 vehicle was looking, a comparison was made between visual confirmation times in 49 cases of near miss incidents (taken from the 104 cases of “negligence of safety confirmation” by drivers using category 1 vehicles on road 1 and under the condition that the approaching vehicle had four wheels and that the direction the driver’s head was facing was gaugeable) and 41 cases of normal driving. The following figure (Figure 5) displays the direction that the driver was looking while driving in the space provided for checking oncoming traffic (the approximately 6 meter space between the stop line and the borderline of the lane for traffic with right of way) and cumulative amount of time the driver spent confirming oncoming traffic as estimated from the direction the driver’s head was facing.

In Figure 5, N stands for the number of vehicles and V stands for the average speed of vehicles while in the space provided for checking oncoming traffic.

Compared to ordinary driving, the visibility time for close calls is short, and the visibility time becomes particularly short in the rightward direction. (Intersecting vehicles include those to the left and right.)

Fig. 5: Total time spent visually confirming by direction for other vehicles while the vehicle protrudes past stop line

Next, Figures 6 and 7 separately compile the number of near miss incidents and cases of normal driving when a category 2 vehicle approached from the right and left where a category 1 vehicle either drove forwards or turned right.
Fig. 6: Total time spent visually confirming by category 1 vehicles when advancing forward. Separated by direction confirmed (near miss incident and normal driving).

Drivers pretty much failed to check rightwards when turning right, ending up in a near miss incident with the right intersecting vehicles.

Drivers checked right and left when turning right, but there were near miss incidents with the left intersecting vehicles.

Drivers normally looked to the right properly when making a right turn.

Fig. 7: Total time spent visually confirming by category 1 vehicles when turning right. Separated by direction confirmed (near miss incident and normal driving).
The following observations were made from these figures.

- Overall, a shorter amount of time was spent visually confirming other traffic in the case of near miss incidents compared with normal driving (Compared with normal drivers, drivers involved in near miss incidents cut short the amount of time spent on visual confirmation for some reason, and take actions that are riskier).
- There was especially a tendency for drivers not to look to the right, as it is an obtuse angle.
- Category 1 vehicles involved in a near miss incident varied greatly in visual confirmation behavior depending on whether they traveled forwards or made a right turn.
- Category 1 vehicles varied greatly in visual confirmation behavior when turning right depending on whether the intersecting vehicle was coming from the right or from the left.
- It is clear that there is not much time for visually confirming vehicles to the right in the case of rightward near miss incidents.
- When making a right turn, near miss incidents occur with vehicles intersecting from the left despite the driver visually confirming traffic leftwards.
- In regards to near miss incidents with vehicles intersecting from the left, because the timing in which the driver visually confirms traffic to the left, or because it is necessary for the driver to rotate their line of vision nearly 130 degrees in order to check for oncoming vehicles (in the event of a right turn the angle could be larger if the vehicle was pointed to the right), or due to other reasons, it is possible that drivers fail to visually confirm oncoming traffic despite their intention to do so.

(2) Visual Confirmation Behavior

It is possible to infer causes for near miss incidents to a degree from looking at the ratio of visual confirmation times separated by direction, and we have applied classifications for the behavior of the direction of the driver’s face during near miss incidents individually for drivers of category 1 vehicles. As a representative example, Table 3 shows results of behavior classifications for near miss incidents with vehicles intersecting from the right.

<table>
<thead>
<tr>
<th>Classifications of causes</th>
<th>Behavior and its meaning</th>
<th>Direction faced just before near miss incident</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Looked rightwards too early</td>
<td>Became careless because did not (or could not) look to the right</td>
<td>Forward or right</td>
<td>4</td>
</tr>
<tr>
<td>Looked rightwards too late</td>
<td>Looked to the right while entering intersection</td>
<td>Right</td>
<td>3</td>
</tr>
<tr>
<td>Did not look rightwards due to preoccupation with the left side</td>
<td>Looked at a direction other than to the right while entering intersection (Did not look rightwards at all after passing the stop line)</td>
<td>Left</td>
<td>3</td>
</tr>
<tr>
<td>Did not look rightwards due to preoccupation with the forward direction</td>
<td>Looked forwards while entering the intersection (Did not look rightwards at all after passing the stop line)</td>
<td>Forwards or broad right</td>
<td>2</td>
</tr>
<tr>
<td>Inadequate confirmation of the right side</td>
<td>Could not see vehicles intersecting from the right for unspecified reason</td>
<td>Right or forwards</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Driving fast and did not confirm oncoming traffic adequately</td>
<td>Right or forwards</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

The results show that the most prevalent cause of near miss incidents with vehicles intersecting from the right was that the timing in which the driver looked rightwards was too early. The driver made a quick check to the right (broad right) from an area shaded by buildings with insufficient visibility of objects far away and found no intersecting vehicles (or could not see any vehicles), so the driver carelessly neglected to reconfirm oncoming traffic from an area where visibility of objects far away was sufficient.

The next most prevalent cases were when “the driver looked rightwards too late” and when “the driver did not look rightwards because s/he was worried about the left.” These cases are due to the fact that the rightward direction is at an obtuse angle from the driver, and when the driver approaches the intersection, because they are able to see forwards and broadly rightwards to some extent, they assume that they have confirmed rightward traffic sufficiently and concentrate on the acute angle to the left. These three cases make up more than 60% of the total causes.
For reference, Figure 8 displays three examples of visual confirmation behavior in the extreme case where drivers were worried about the left and did not look rightwards.

The classifications provided in Table 3 are classifications for a driver’s visual confirmation behavior. However, these classifications correspond to the content of “negligence of safety confirmation,” which is generally used in classifying human related collision causes. Therefore, it is believed that these classifications can contribute to categorizing and considering “negligence of safety confirmation” in greater details.

On the other hand, by observing traffic conditions at the intersection and the environment of the driver at the time of his/her visual confirmation behavior, one may see instances where the following type of independent factors have induced such visual confirmation behavior. It has become clear that there are other multiple factors involved in approximately half of the classified cases despite the existence of intersecting vehicles on both the left and right. For example, there are following cases:

- In the middle of deciding whether to continue forwards or turn right (inferred from the fact that the driver turned off the right turn signal after once turning it on)
- Talking with another passenger
- The driver wants to turn right before the driver in the directly opposing vehicle (inferred based on the timing of each driver)
- Decided a vehicle would not come from the side after observing the opposing vehicle drive past (However, the timing is a little off, and this can be considered wishful thinking)

While 85% of the behavior of drivers can be classified as “negligence of safety confirmation” on the surface, in a few instances therein, the driver who incited the collision mainly answered that there were multiple causes for the collision on their personal statement. Thus, it is thought that the percentage of ‘negligence of safety confirmation’ on the actual collision statistics has been reduced to 78%.

(3) Vehicle behavior when approaching the intersection
A survey was conducted on the behavior of category 1 vehicles approaching and reducing speed at intersections. Figure 9 displays three different cases. One, the case where intersecting vehicles stop as they approach each other (not a near miss incident) and thus display normal driving; two, a case of normal driving where the intersecting vehicle is far away and thus the category 1 vehicle passes ahead of them; and three, a case of a near miss incident. Additionally, three different colors are used to divide the speed at which vehicles approached each other during near miss incidents into fast, medium, and slow.

The horizontal axis of the figure is the distance of the vehicle to the intersection (0 m is the stop line, and approximately -6 m is the position where a vehicle may protrude past the stop line) and the vertical axis displays the speed (It appears as if vehicles reduced speed after entering the intersection in normal driving, however this is due to an error in the measurement border. The vehicles do not actually reduce speed).
Fig. 9: Behavioral comparison of approaching category 1 vehicles

The following observations were made from these figures.
- There is no difference in the behavior in which a vehicle approaches an intersection in the case of a near miss incident and in normal driving. The cause of near miss incidents is in the behavior of the vehicle after they approach the intersection.
- The behavior of vehicles beginning to accelerate in the case of a near miss incident is the same as that of vehicles in normal driving when the intersecting vehicle is approaching from afar. It can be seen from this behavior that the driver is overlooking the intersecting vehicle.
- At a position 3-4 meters before the position a driver is able to protrude past the stop line, the driver decides whether to stop or to continue into the intersection without slowing down. Near miss incidents are caused by overlooking other vehicles during this decision making process.
- For the group of vehicles involved in near miss incidents approaching at high speeds (marked in orange), there is an equal number of vehicles that accelerate compared to those that continue slowing down at the above position. However, this is because the vehicles were originally approaching the intersection at a high speed and there were instances where they entered the intersection while decelerating. This means that the driver considers safety and does not accelerate. However, because they put off the decision to accelerate, they end up in a near miss incident.

The following were also gathered, although the figures are omitted.
- The ratio of vehicles that failed to temporarily stop (category 1 vehicles that failed to slowdown or stop once, and maintained a speed of at least 15 km/h) compared to the total number of vehicles is 0.34%. Among these vehicles, the percentage of those involved in a near miss incident was high, at 9.8%. Thus, it can be said that failing to stop is one cause of near miss incidents.
- The number of category 1 vehicles involved in a near miss incident that came to a temporary stop (vehicles that stopped at the position where vehicles may protrude past the stop line are also defined as a temporary stop) was 28 (however, most of these cases were because they stopped due to a leading vehicle) and the ratio of those that stopped to those that did not stop was approximately 50%. Thus, it can be said that forcing a category 1 vehicle
to temporarily stop does not necessarily eliminate the chance for a near miss incident.

5. Reflecting this research onto a service approach

Approaches for a head-on collision safety support service can be divided largely two ways based on the variety of information to be provided to the driver.

<table>
<thead>
<tr>
<th>Service Approach</th>
<th>Information Provided</th>
<th>Effect</th>
<th>Implementation Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic head-on collision service</td>
<td>Information on the presence of intersecting vehicles detected by a sensor (dynamic (real-time) information)</td>
<td>Prevents the overlooking of oncoming vehicles and helps to drivers to stop properly</td>
<td>Concentrated implementation in areas with frequent collisions</td>
</tr>
<tr>
<td>Static head-on collision service</td>
<td>Provision of information on the location of stop lines, etc. using non-changing information (static information) such as maps</td>
<td>Prevents the overlooking of intersections and stop lines</td>
<td>A service for simple and widespread use (partnered with car navigational systems)</td>
</tr>
</tbody>
</table>

The service described in the hypotheses at the beginning of this document corresponds with a dynamic head-on collision service. Utilizing the data collected, a design value has been calculated for a both effective and user receptive service that could be provided at this specific intersection.

Figure 10 displays the results of research conducted on what speed and distance a category 2 vehicle would need to be from the intersection for a category 1 vehicle to pass ahead of the category 2 vehicle, or stop and let the category 2 vehicle go first. The horizontal axis plots the distance from the point where the category 1 and 2 vehicle are to intersect, measured from the position of the category 2 vehicle at the instant when the category 1 vehicle is visually confirming to the left and right while in the area protruding the stop line. The vertical axis plots the speed of the category 2 vehicle at that same instant.

The blue colored dots represent when the category 1 vehicle passed ahead (accelerating condition) of the category 2 vehicle. The green dots represent when the category 1 vehicle stopped (stopping condition). The red dots represent a near miss incident. Because it is not precisely clear where the trends for the accelerating condition and stopping condition begin, borders have been drawn separating two dots for the accelerating condition and the same number of dots for the stopping and near miss incident conditions so that they each fit in the same area (within the yellow circles), and a straight line has been drawn to pass through the origin of the graph.

The data collected tells us that category 2 vehicles reach the intersection in question from the right in between 4
and 5 seconds. This paper makes the assumption that 4.6 seconds marks the border where a category 1 vehicle would choose to either pass ahead of or wait for the approaching vehicle. This means that making the driver wait longer than this time would be too long of a time to wait, and would reduce service receptivity. Therefore, 4.6 seconds is the optimal length of time for a warning signal.

As a service approach used here as premises for consideration is a lighter infrastructure, the service will adopt an approach of a simple sensor (only detects the passing of a vehicle) being placed at a location x meters from an intersection on the category 2 vehicle side, then, after the category 1 vehicle has been detected, a signal lasting for y amount of time will be transmitted to the category 1 vehicle between the road and vehicle to alert the driver that another vehicle is “present.” Thereafter, the device in the category 1 vehicle will output a warning signal (evoking a beeping sound) while receiving the transmission indicating the other vehicle is “present.”

When considering avoiding collisions, it is conceivable that a sensor simply be placed 4.6 seconds (calculated using a certain assumed speed) before the point when two vehicles would intersect and then output a warning signal for 4.6 seconds following the vehicle passing the sensor. However, this type of service would not be useful, because vehicles traveling at speeds slower than those hypothesized would take a longer time to reach the intersection after passing the sensor, and would thus have to wait longer, degrading the receptivity of the service.

Therefore, a distance will be ensured that would allow the category 2 vehicle to stop in time even after noticing that a category 1 vehicle has lunged in front of them. To put it differently, a warning signal will be sent to the category 1 vehicle in the event the category 2 vehicle is approaching a distance where it is not possible for them to stop.

95% of the actual speed of a category 2 vehicle at this intersection is 48 km/h. Adopting this measurement, it is postulated that the emergency deceleration of the category 2 vehicle would be 0.5 G, and from the following formula,

\[ t = \frac{V}{a} \quad (V: \text{Initial speed}; \quad a: \text{deceleration}) \]

we know that braking time is approximately 2.7 seconds. Then, presuming that it would take 1.0 second from the time the driver visually confirmed the category 1 vehicle lunging before them until the time the driver began to step on the brake, 1.0 second is added to the braking time to total 3.7 seconds. Thereafter, from the following formula,

\[ L = Vt + \frac{1}{2}at^2 \quad (t_r: \text{reaction time}) \]

we know that a stopping distance of approximately 31 meters would allow the category 2 vehicle to stop just before a collision.

Therefore, the placement of the sensor shall be 31 meters calculated from the point that the two vehicles would collide (around in the middle of the intersection).

The absolute minimum required length for the warning signal is the 3.7 second stopping time for the category 2 vehicle. However, in order to allow enough time for this to be functional for vehicles traveling at speeds less than 48 km/h, the 4.6 second long warning signal as mentioned before from a receptivity standpoint will be adopted. In this case, the speed at which a vehicle would travel 31 meters in 4.6 seconds would be 24 km/h. Therefore, vehicles traveling at less than 24 km/h would not be involved in a major collision and would thus be omitted from the service. This shows that a warning signal of 4.6 seconds works well while simultaneously solving the issue of receptivity.

The design value for the sensor placement is x=31 m, and the output length of the warning signal is y=4.6 seconds.

6. Conclusion

By collecting data of vehicle behavior at an actual intersection during a long-term, we have reached a new insight into near miss incidents at unsignalized small intersections. Moreover, while simultaneously validating the hypotheses established at the beginning of this document, we were able to gain clues into analyzing “negligence of safety confirmation,” the human-related cause for 3/4 of head-on collisions, more thoroughly.

Furthermore, we attained a solution for a realistic design that would allow for both effectiveness and receptivity regarding head-on collision prevention service.